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(54) Title: DEVICE AND METHOD FOR TIME-RESOLVED OPTICAL MEASUREMENTS

$$Y = \frac{FS}{F_{SL1}}$$

$$F = \frac{F_{SL1} + F_{SL2} - S}{F_{SL2} F_{SL1}}$$
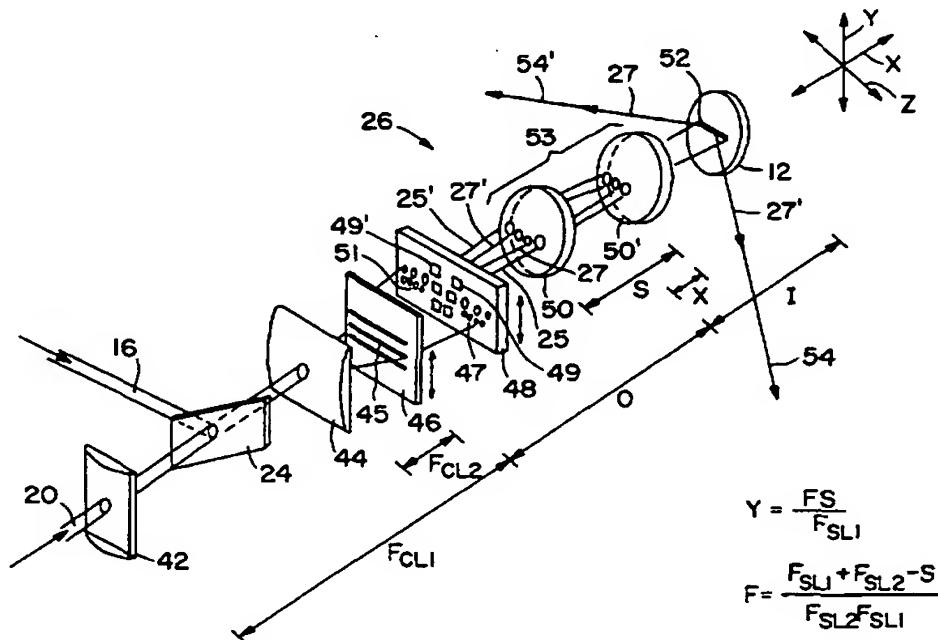
(57) Abstract

An optical modulating system (26) allows modulation of a single light beam (16) with a spatially filtering mask (47) to form a spatially periodic, time dependent excitation field. Once generated, the field can be used to induce a transient grating in a sample (12). The optical modulating system (26) is additionally configured to automatically orient a probe beam (20) at the Bragg angle, thereby allowing the intensity of the probe beam (20) to be maximized.

DEVICE AND METHOD FOR TIME-RESOLVED OPTICAL MEASUREMENTS

Field of the Invention

5   This invention relates to the measurement of material properties using time-dependent, spatially varying optical fields.

Background

         Measurement techniques involving optical
10 excitation and detection of material motions are extremely important from both purely scientific and applications-oriented points of view. In particular, techniques such as transient grating spectroscopy or impulsive stimulated scattering use laser light to both
15 excite materials (e.g., polymer films) and to measure the resulting response. In these techniques, two excitation laser pulses are crossed in space and time in the sample. Overlap of the excitation pulses results in optical interference to produce an excitation field which has
20 alternating "light" and "dark" regions, with the overall intensity of the field varying in a sinusoidal manner. The angle between the overlapping pulses determines the spatial frequency, i.e., the wavevector, of the alternating regions. The excitation field can induce a
25 transient grating in the sample through several different mechanisms. For example, optical absorption of the excitation field can create electronic excited states which can decay through the emission of heat or light. For example, in Impulsive Stimulated Thermal Scattering
30 ("ISTS") the optical energy of the light regions of the field is absorbed by the sample, resulting in the deposition of heat which is followed by thermal expansion of the irradiated regions. This results in the launching of coherent, counter-propagating ultrasonic phonons

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having a wavevector with a spatial frequency and
orientation matching the geometry of the excitation
field. The sample can also be excited via a non-
absorptive process. In Impulsive Stimulated Brillion
5 Scattering ("ISBS") or Impulsive Stimulated Raman
Scattering ("ISRS"), for example, the sample is excited
using a spatially varying optical intensity pattern, but
the photons have a wavelength that is not absorbed by the
film. In these techniques, optical energy is coupled
10 directly into the film's acoustic field to excite
acoustic processes. The excitation process takes
advantage of the inherent spectral line width of the
excitation pulses; higher-frequency photons from each
excitation pulse are annihilated to create lower-
15 frequency photons in the opposite excitation pulse.
Counter-propagating acoustic phonons of the difference
frequency and wavevector are then generated in the
medium.

In ISTS, ISRS, ISBS, and other transient grating
20 techniques, phonon propagation or electronic events may
continue after the excitation pulses leave the sample,
causing a time-dependent, spatially periodic variation in
the material properties in the excited region. Because
the relevant optical properties of the material are
25 functions of the magnitude of this response, the time
dependence of the excited region can be detected with an
optical probe beam. The excited region of the sample
functions as a transient diffraction grating, resulting
in diffraction and modulation of the incident probe beam
30 to produce a signal beam which can be detected and
analyzed. In order to determine a particular property of
the sample, such as the elastic moduli, it may be
necessary to measure the sample's dispersion (i.e., the
wavevector-dependent r sponse).

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In order to form the spatially varying optical
excitation field using the conventional transient grating
methodology, the excitation beam is split into two beams,
which are then recombined in the sample using optical
5   components such as mirrors, beam-splitters, lenses and
mechanical delay stages. These components may also be
used to adjust the angle between the excitation beams.
Additional optical components are used to accurately
adjust the angle, spatial overlap, and timing of the
10   probe beam with respect to the excitation beams.
However, even after careful adjustment, the signal
diffracted by the induced transient grating is often
weak, making both alignment and detection difficult.

Summary

15   In one aspect, the invention provides a method and
apparatus for determining a property of a sample using
the steps of: (a) providing a beam of radiation, and then
passing the beam through a pattern on a diffracting mask
to form at least two excitation sub-beams; (b)
20   overlapping at least two excitation sub-beams on a region
of the sample with an imaging system to generate a
spatially varying optical field which excites a transient
grating in the region of the sample; (c) irradiating the
transient grating with a probe beam oriented so that at
25   least a portion of the probe beam is diffracted by the
transient grating; (d) detecting the diffracted portion
of the probe beam with an optical detector to generate a
light-induced signal; and (e) analyzing the light-induced
signal from the optical detector to determine the
30   property of the sample.

By "sub-beam", as used herein, is meant an optical
field resulting from diffraction of either an excitation
or probe beam. The excitation and probe beams may have
the same or different wavelengths; both beams may be
35   partially absorbed by the sampl .

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In preferred embodiments, the diffracting pattern includes alternating light-modulating regions having at least one spatial frequency, and the excitation beam is separated into at least a zeroth, +1, and -1 excitation
5   sub-beam following diffracting off of the light-modulating regions of the diffracting pattern. In this case, the overlapping step may further include the step of passing at least the +1 and -1 excitation sub-beams through the imaging system (e.g., a lens or series of
10 lenses) prior to overlapping these sub-beams on the sample. The imaging system then images at least one of the spatial frequencies of the light-modulating regions of the diffracting pattern onto the sample to form the spatially varying optical field. Preferably, at least
15 one of the spatial frequencies of the light-modulating region and the spatial varying optical field are equivalent.

In still other preferred embodiments, the probe and excitation beams are made collinear prior to step
20 (a). In this case, step (a) further comprises the step of separating the probe beam into at least two probe sub-beams by passing the probe beam through the diffracting pattern on the first mask. Here, the probe sub-beams preferably pass through the imaging system prior to
25 irradiating the grating induced in the region of the sample.

In other preferred embodiments, the excitation beam is focussed (e.g., cylindrically focussed) onto the diffracting pattern prior to step (a). In addition, the
30 imaging system is preferably a 1:1 imaging system. In this embodiment, the probe beam irradiates the transient grating at the Bragg angle.

In still other preferred embodiments, between steps (b) and (c), the excitation sub-beams are spatially
35 filtered with a second mask. Preferably, the first and

second masks are contained in a single unit, and the spatial filtering transmits the +1 and -1 excitation and probe sub-beams.

In other embodiments, the analyzing step further
5   includes determining the dispersion of the sample. The dispersion may be used to determine the mechanical (e.g., adhesion, elastic moduli, stiffness, residual stress, and density), thermal, optical, or electronic properties of the sample. In this embodiment, the dispersion may be
10   determined following the step of inducing multiple transient gratings in the sample with a single spatial varying optical field having multiple spatial frequencies. Alternatively, the dispersion is determined following the steps of sequentially inducing multiple
15   transient gratings in the sample with multiple spatial varying optical fields, each of which has a single spatial frequency.

In another aspect, the invention provides a method of diffracting a probe beam off a sample. The method
20   includes: (a) providing a beam of radiation, and then passing the beam through a pattern on a diffracting mask to form at least two excitation sub-beams; (b) overlapping at least two excitation sub-beams on a region of the sample with an imaging system to generate a
25   spatially varying optical field which excites a transient grating in the region of the sample; and (c) irradiating the transient grating with a probe beam oriented so that at least a portion of the probe beam is diffracted by the transient grating.

30   In another aspect, the invention provides an apparatus for diffracting a portion of a probe beam off a sample. The apparatus includes means for generating a probe optical beam and an excitation optical beam orientated along an optical axis, and a first diffracting
35   mask including an optical diffracting patt rn. The

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diffracting pattern is positioned al ng th optical axis
and is configured so that, when irradiated with the
excitation beam, the pattern diffracts the excitation
beam to generate at least two excitation sub-beams. The
5 apparatus also include an imaging system containing at
least one lens positioned along the optical axis. The
imaging system is configured to focus the excitation sub-
beams onto a region of the sample to generate a spatially
varying optical field which excites a transient grating
10 which allows partial diffraction of the probe beam.

        In preferred embodiments, the diffracting pattern
includes a series of opaque regions spaced by a distance
which allows diffraction of visible or infrared
radiation. Alternatively, the diffracting pattern may
15 include a series of regions etched to a depth and spaced
by a distance which allows diffraction of visible or
infrared radiation. Preferably, the diffracting mask
includes a plurality of diffracting patterns.

        In another preferred embodiment, the apparatus
20 further includes a second, spatially filtering mask which
includes a pair of openings. The openings are positioned
along the optical axis so that the spatially filtering
mask allows spatial filtering of the diffracted
excitation sub-beams. Preferably, the spatial filtering
25 mask includes a plurality of pairs of openings, and the
diffracting and spatial filtering masks are contained in
a single unit.

        Embodiments may include one of the following
advantages. For example, a simple, linearly configured
30 optical system is provided which modulates a single beam
with a filtering mask to form a spatially periodic, time-
dependent excitation field which can then be used to
induce a transient grating in a sample. The system can
be additionally configured to orient a probe beam at the
35 Bragg (or phase-matching) angle using a simple optical

arrangement. This allows the diffraction efficiency of the induced grating, and the intensity of the diffracted probe beam, to be maximized.

Optical alignment of the system is both simple and 5 quick. The user need only make the probe and excitation beam collinear prior to interaction with the masks. The masks and imaging optics are used to define the excitation pattern (i.e., wavevector) at the sample, set the timing such that the excitation pulses arrive at the 10 sample at the same time, set the probe angle of incidence at the Bragg angle, and provide a beam to allow for facile signal location and amplification. During operation, the wavevector of the excited phonons can be adjusted simply by translating the masks. These masks 15 are the only moving parts in the system, allowing the measurement technique to be easily automated while reducing the number of optics required in the optical modulating system.

When a thick grating is formed in the sample, 20 automatic setting of the Bragg angle allows the diffraction efficiency of the grating to be maximized. This is particularly important, as diffraction efficiency for these gratings falls off rapidly at angles even within a fraction of a degree of the Bragg angle, 25 regardless of the amplitude of the material response. Once irradiated, the optical modulating system generates multiple probe beams at the sample. One probe beam can serve to probe the transient grating, while another probe beam may serve as a "finder" beam to determine the 30 position of the signal beam. This makes the practical matter of aligning weak signals into a detector trivial since the finder beam has a large optical intensity, and is thus easy to locate. This same finder beam may also be used for heterodyne amplification of weak signal 35 beams.

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Moreover, with this invention the excitati n fields are not limited to simple sinusoidal patterns. For example, in some cases it may be desirable to induce material motions with more complex geometries or to

5 simultaneously excite material motions at multiple wavevectors using complex mask patterns.

Brief Description of the Drawings

Fig. 1 is a schematic drawing of the optical elements of a sample-measuring device according to the

10 invention;

Fig. 2 is a perspective view of the optical modulating system of the sample-measuring device;

Fig. 3 is an expanded view of the masks and imaging optics of the optical modulating system;

15 Figs. 4A and 4B are, respectively, a graph showing the spatial dependence of the modulating regions of the mask, and the spatial dependence of the excitation field generated using the diffracting mask of the optical modulating system;

20 Figs. 5A, and 5C are, respectively, the spatial dependencies of the excitation and probe fields after being diffracted by the first mask but prior to being filtered by the second mask, and after being diffracted by the first mask and filtered by the second mask;

25 Fig. 5B is the spatial transmission function of the spatial filtering mask;

Figs. 6A and 6B are, respectively, plots showing the time dependence of the diffracted signal from a thin grating generated in a film sample using the optical

30 modulating system;

Figs. 7A and 7B are, respectively, plots showing the time dependence of the diffracted signal from a thick grating generated in salol using the optical modulating system.

Detailed Description

Referring to Fig. 1, an optical measurement system 10 used to excite a sample 12 and probe the resulting motions includes excitation 14 and probe 18 lasers which
5 produce, respectively, excitation 16 and probe 20 optical beams. The excitation beam is composed of a sequence of pulses, while the probe beam may contain sequences of pulses, or alternatively, optical waveforms having relatively long temporal durations. Prior to irradiating
10 the sample, the excitation beam 16 is reflected by a pair of optics 22, 24 which are highly reflective at the excitation beam wavelength and are oriented to direct the beam into an optical modulating system 26. The second high-reflecting optic 24 preferably reflects the
15 excitation beam efficiently, and is partially transparent to the probe beam. For example, this optic may be a beamsplitter, dichroic mirror, or a thin film polarizer. The optic 24 allows the probe beam 20 to be oriented collinearly with the excitation beam 16 prior to entering
20 the optical modulating system 26.

The optical modulating system 26 modulates the single excitation beam 16 to produce a pair of spatially modulated excitation sub-beams 25, 25' which are recombined within or on the surface of the sample. The
25 optical modulating system is configured so that the timing and spatial positions of the pulses in the excitation sub-beams 25, 25' are overlapped, resulting in optical interference between the two sub-beams to produce a spatially varying optical field which is then used to
30 excite the sample 12. The single probe beam 20 is also spatially modulated by the optical modulating system 26, resulting in the generation of a pair of probe sub-beams 27, 27' which, when the probe wavelength is different than the excitation wavelength, spatially separate from
35 the excitation sub-beams 25, 25'. During the measurement

process, both probe sub-beams 27, 27' are diffracted from
the transient grating excited in the sample, resulting in
the generation of a pair of signal beams. A single
signal beam 28 is measured by an optical detection system
5   30, which may include, for example, a photodetector
electrically connected to a transient recording device.
Measurement of the diffracted signal results in the
generation of a status signal 32 which may be further
processed by a computer and used to evaluate the material
10 properties of the sample 12.

         The elements of the optical modulating system 26
generate the spatially varying optical excitation field
from a single excitation beam, and allow the Bragg angle
of incidence of the probe beam to be automatically set.
15 This permits data to be collected at a variety of
excitation wavevectors with minimal alignment, thereby
allowing the dispersive characteristics of the sample to
be easily measured. Measurement of the dispersion
allows, for example, material properties such as modulus
20 of elasticity, thermal diffusion, adhesion, electronic
transport, and stress to be determined in both bulk and
thin film samples. In addition, the optical modulating
system 26 has a simple, compact design with a minimal
number of optical elements, and only one movable element.
25 This allows the sample-measurement process to be easily
automated and performed in a rapid fashion.

         Referring now to Figs. 2 and 3, in a preferred
embodiment, the elements of the optical modulating system
26 are preferably disposed in a linear arrangement along
30 an axis (indicated in the figure by the x axis) to allow
spatial modulation of the collinear excitation 16 and
probe 20 beams. Prior to passing through the optic 24,
the probe beam 20 is transmitted through a first
cylindrical lens 42 (having a focal length indicated by
35 "F_{cll}") which focuses the beam so that it is elongated

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along the z axis. Once overlapped, the excitation 16 and
probe 20 beams are focussed with a second cylindrical
lens 44 (having a focal length indicated by "F$_{cl2}$") onto a
patterned region 45 of a first mask 46 which spatially

5 filters both beams. The mask 46 is positioned at the
focal point (F$_{cl2}$) of the second cylindrical lens 44 so
that the excitation beam is focussed to an elongated,
elliptical spot which extends along the pattern 45, while
the probe beam, previously focussed with the first

10 cylindrical lens 42, is focussed to a small circular spot
in the center of the elongated excitation spot.

The patterned region 45 on the mask 46 may
include, for example, an alternating periodic pattern of
transmissive and opaque regions which filter the

15 intensity of the cylindrically focussed excitation beam.
Alternatively, the pattern may include periodic regions
of transparent glass etched to varying depths (e.g., $\lambda/4$)
which filter the phase of the incident excitation field.
In both cases, interaction of the excitation 16 and probe

20 beams with the patterned region 45 causes diffraction
of these beams to form a series of sub-beams
corresponding to different diffractive orders.

After being dispersed and separated following
diffraction from the first mask 46, the diverging

25 excitation and probe sub-beams are spatially filtered by
a second mask 48 which is displaced along the x axis from
the first mask by a distance which allows clear spatial
separation of the excitation and probe diffractive
orders. This is the case when the wavelengths of the

30 excitation and probe beams are different; when the
wavelengths are the same, the excitation and probe sub-
beams are not separated. The second mask 48 includes
multiple pairs of openings 49, 49' which allow
transmission of the selected diffractive orders from both

35 the pump and probe beams. Preferably, the second mask is

configured so that each pair of openings corresponds to a separate patterned region on the first mask. The pairs of openings are brought into the beam path by translating the second mask vertically.

5   Each diffractive order represents a different Fourier component of the spatially varying pattern region 45 of the first mask 46. For example, the +1 and -1 orders of the excitation and probe fields are first order Fourier components, while higher (e.g., +/-2, +/-3) and

10 lower (e.g., the zeroth order) diffractive orders represent, respectively, high-frequency and DC Fourier components. Spatial filtering by the second mask 28 thus allows selected Fourier components of the diffracted field to pass; these components are then recombined on

15 the sample to form the desired excitation pattern.

The excitation 25, 25' and probe 27, 27' sub-beams are transmitted through the mask 40. The diffracted sub-beams diverge at angles of Θ (probe sub-beams) and ϕ (excitation sub-beams), with each sub-beam representing

20 either the positive 47 (e.g., +1, +2) or negative 51 (e.g., -1, -2) orders of diffraction. The diffractive process depends on the spatial separation d (i.e., the "wavelength") of the light-modulating regions of the patterned region, and on the wavelengths of the incident

25 excitation and probe fields:

$$2d \sin (\Theta) = n\, \lambda_{probe}$$
$$2d \sin (\phi) = n\, \lambda_{excitation} \qquad (1)$$

where n is the diffracted order. Thus, the divergence of the sub-beams is determined only by the excitation and probe wavelengths and the geometry of the patterned region.

30   Recombination of the transmitted diffracted orders of the excitation and probe b ams is accomplished using an imaging system 53. This allows: 1) spatial

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recombination of selected excitation sub-beams, resulting
in the generation of a spatially varying optical field in
or on the surface of the sample; and 2) the probe sub-
beams to be automatically oriented so that they arrive at
5   the sample at the Bragg (i.e. phase-matching) angle. The
imaging optics may consist of a single lens (Fig. 3) or
two separate lenses 50, 50' having focal lengths of,
respectively, F_{sl1} and F_{sl2} (Fig. 2).

In the case where two separate lenses are used,
10 the separation between the lenses, indicated by S in the
figure, allows the imaging system to be used as a
telescope to magnify or demagnify the field imaged onto
the sample. This allows the spatial scale or size of the
interference pattern at the sample to be adjusted by
15 changing the separation between the two imaging lenses.
For example, if the interference pattern is demagnified
on the sample, the separation between light and dark
regions will be decreased, resulting in an increase in
the excitation wavevector. Conversely, if the pattern is
20 magnified, the separation between light and dark regions
is increased, and the spatial frequency of the excitation
wavevector is decreased.

The actual imaging process occurs at a plane
defined as the image plane, which is determined by the
25 focal length of a single lens or the equivalent focal
length of the multiple-lens (e.g., a two-lens) imaging
system. In the two-lens system, the effective focal
length F of the imaging system is a function of F_{sl1},
F_{sl2}, and S:

$$F = \frac{F_{sl1} + F_{sl2} - S}{F_{sl1}F_{sl2}} \qquad (2)$$

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The effective "position" X of the imaging system along
the x axis is displaced from the second lens 50' by a
distance related to F, S, and the focal length F_{ell} of the
first lens 50:

$$X = \frac{FS}{F_{ell}} \qquad (3)$$

5   The patterned region on the mask, which represents
the object to be imaged, is displaced from X by a
distance O. The displacement I of the sample from X
represents the displacement of the image plane, and is
related to F and O by the equation:

$$\frac{1}{F} = \frac{1}{O} + \frac{1}{I} \qquad (4)$$

10 which can be rewritten as

$$I = \frac{OF}{(O-F)} \qquad (5)$$

Thus, during imaging, the degree of magnification or
demagnification M of the object, defined as $M = I/O$, can
be adjusted by choosing a lens combination which gives
the desired value of F, and by placing the sample at the
15 appropriate distance I from X.
        In addition to imaging particular Fourier
components of the patterned region onto the sample, the
imaging optics can be configured to focus the transmitted
probe beams onto the induced grating at the Bragg angle.
20 Referring now to Fig. 3, in order for the probe beam 16
to satisfy the Bragg phase-matching criteria, excitation
20 and probe 16 beams having wavelengths λ_{ex} and λ_{pr} are
spatially overlapped along an optical axis of the
modulating system prior to irradiating the patterned

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regi n 45 on the first mask 46. (In this embodiment, a
single imaging lens is used, although it is understood
that a multiple-lens imaging system, as shown in Fig. 2,
may also be used.) Diffraction generates at least a
5 zeroth 65, +1 47, and -1 51 diffracted orders, with each
order containing the excitation 25, 25' and probe 27, 27'
sub-beams. The excitation and probe beams are separated,
respectively, by angles ϕ and θ from the optical axis of
the system. The second mask 48 is used to spatially
10 filter the zeroth order 65 and transmit the +1 47 and -1
51 orders onto an imaging lens 50 which is spaced a
distance D from the first mask 46. The diffracted
excitation and probe beams irradiate the lens,
respectively, at distances z_1 and z_2 from the optical
15 axis. The beams are imaged onto the sample 12 which is
spaced a distance D from the lens 50. In this
configuration, the distances D and D' are related by the
equation

$$\frac{1}{D'} = \frac{1}{f} - \frac{1}{D} \qquad (6)$$

which can be rewritten as

$$D' = \frac{Df}{(D-f)} \qquad (7)$$

20 Following focussing by the lens 50, the diffracted orders
47, 51 containing the probe and excitation sub-beams
converge on the sample with angles θ' and ϕ', which can
be related to z_1, z_2, D, and D':

$$\tan\phi' = \frac{z_1}{D'} = \frac{D\tan\phi}{D'} \qquad (8)$$

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$$\tan\theta' = \frac{z_2}{D'} = \frac{D\tan\theta}{D'} \qquad (9)$$

In can be shown, then, that

$$\frac{\sin\theta'}{\sin\phi'} = \frac{\lambda_e}{\lambda_p} \sqrt{\frac{M^2[1-(\frac{\lambda_e}{2d})^2] + (\frac{\lambda e}{2d})^2}{M^2[1-(\frac{\lambda_p}{2d})^2] + (\frac{\lambda p}{2d})^2}} \qquad (10)$$

To satisfy the phase-matching criteria, it is required that

$$\frac{\sin\theta'}{\sin\phi'} = \frac{\lambda_e}{\lambda_p} \qquad (11)$$

Two conditions must be met, therefore, for the Bragg
5 phase-matching angle to be set independently of the mask
pattern.

These conditions are:
        M = 1 (i.e., a 1:1 imaging system), or the
case when

$$M > \frac{(\frac{\lambda_e}{2d})}{\sqrt{1+(\frac{\lambda_e}{2d})^2]}} \qquad (12)$$

10 and

$$M > \frac{(\frac{\lambda_p}{2d})}{\sqrt{1+(\frac{\lambda_p}{2d})^2]}} \qquad (13)$$

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hold for the imaging system. In addition, in the case
where the excitation and probe wavelengths are
equivalent, the Bragg angle for the system is
automatically set using the optical modulating system.

5   Thus, by making the excitation and probe beams
collinear prior to entering the optical modulating
system, the probe beam is diffracted by the first mask to
produce a pair of probe sub-beams which, when conditions
(1) or (2) are satisfied, are automatically oriented at
10 the Bragg angle.

          Following interaction with the transient grating,
the sub-beams incident on the sample are diffracted to
generate a pair of signal beams 54, 54' which are
spatially overlapped with the residual portions (i.e.,
15 the non-diffracted components) of the opposing probe sub-
beams. The presence of both diffracted (i.e., signal)
and reflected (i.e., residual probe) beams is
advantageous for two principal reasons. First, the
residual beam may be used as a reference or "finder" beam
20 which allows the spatial location of the signal (which is
often weak and hard to see by eye) to be determined,
thereby simplifying alignment of the diffracted beam into
the detection apparatus. Second, the presence of both
signal and reference beams allows for heterodyne
25 amplification of the signal beam, i.e., the high-
intensity residual beam may be used to optically
interfere and "beat" against the weak diffracted signal
beam, resulting in amplification of the signal. Although
Figs. 2 and 3 show a sample which reflects the incident
30 probe beams, transmissive samples may be monitored; the
relative geometries for the excitation, probe, and signal
beams are similar for such samples.

          Referring now to Figs. 4A and 4B, the patterned
region 68 of the first mask of the optical modulating
35 system interacts with the incident excitation field to

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produce multiple orders of excitation sub-beams, which
can then be recombined to generate a spatially varying
optical field at the sample. In a preferred embodiment,
the patterned region 68 consists of alternating, equally
5   spaced opaque regions 70, each having a width 76, which
are separated from each other by neighboring transparent
regions 72. The modulating regions 70 of the mask may
consist, for example, of a series of opaque lines formed
by deposition of an absorbing material, such as a thin
10   metal film, on a glass substrate which is transparent to
the excitation and probe laser wavelengths. Masks having
this "square-wave" transmission profile include, in
theory, an infinite number of spatial frequency
components, and will thus produce an infinite number of
15   diffracted orders, with the intensity of each order
falling off as

$$I \sim [[\frac{\sin(\frac{N \pi d p}{\lambda})}{\sin(\frac{\pi d p}{\lambda})}]^2 \frac{\sin(\frac{\pi s p}{\lambda})}{\frac{\pi s p}{\lambda}}]^2 \qquad (14)$$

where λ is the wavelength of light, $p = \sin \theta$, where θ is
the diffracted angle, n is the diffracted order, and d is
the width of the opaque regions, and s is the distance
20   separating these regions. Multiple orders appear because
Fourier decomposition of the square-wave pattern of the
mask yields an infinite additive series of sine wave
harmonics, with the fundamental frequency of the series
equivalent to the inverse of the spacing 74.
25   Alternatively, the modulating regions 70 of the
mask may be fabricated to have a different thickness
relative to the transparent regions 72 so as to spatially
modulate the phase of the excitation field. For example,
if the region 70 of the pattern 68 is etched so that its
30   thickness is $\lambda/2$ less than th thickness of the adjacent

regions 72, then the portions of the cylindrically
focussed excitation spot which propagate through regions
70 will be π out of phase relative to the adjacent
portions of the excitation field following propagation
5 through the mask. Phase modulation, as opposed to
amplitude modulation, may be desirable as a way of
modulating the excitation field as the intensity of the
field is not attenuated by the mask.

   Both the amplitude and phase-modulating masks
10 diffract the excitation field into multiple sub-beams.
Once when recombined in or on the sample, the excitation
sub-beams result in an optical interference pattern in
which the spatial separation 86 of the light 82 regions
(or, alternatively, dark regions 84) of the optical
15 intensity pattern 80 is a function of the spacing 74 in
the patterned region 68 and, as described above, the
focal and geometric properties of the imaging system.

   In general, the spacing 74 of the regions 70 on
the pattern 68 is within a factor of between 1 and 1000
20 of the wavelength of the optical field 80 which is imaged
in the sample; typically the spacing is between 1 and 100
microns. A single mask may include multiple patterns,
with each pattern having a different spacing 74 between
light-modulating regions 70 and thus corresponding to an
25 excitation field having a different wavevector. The
multiple patterns are preferably placed as close together
as possible; for typical beam geometries, individual
patterns are preferably separated by distances of between
about 300-700 microns. The width 76 of the modulating
30 regions is typically between 0.2 and 1.5 times the
separation distance 74.

   In the case where it is desirable to excite
multiple acoustic modes in the sample, with each mode
having a separate well-defined wavevector, a patterned
35 region on the mask may be fabricated to include multiple

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low-frequency spatial frequency components (i.e., frequencies other than those used to construct the square wave edges). For example, the mask may have multiple square or sine waves, each having a different
5   periodicity. An excitation field having this pattern will excite multiple modes, allowing the dispersive (i.e., wavevector-dependent) properties of the sample to be determined using a single excitation pulse.

The shape of the modulating regions 70 of the
10   pattern 68 need not have a square-wave profile. For example, the pattern may vary sinusoidally along the z dimension. This geometry, as opposed to the square-wave pattern which essentially requires an infinite number of spatial frequencies to construct the sharp edges of the
15   waveform, contains only a single frequency component equal to the spatial frequency of the sine wave. The intensity of the field diffracted by the sine wave pattern is primarily distributed between a DC component (i.e., the zeroth order) and the +1 and -1 diffractive
20   orders. In this embodiment, therefore, a larger fraction of the incident excitation field is concentrated in the first-order excitation sub-beams.

In another embodiment, multiple masks, each having a different spatial frequency, may be stacked
25   sequentially along the z axis and used to generate an optical field containing multiple excitation wavevectors. In addition, other patterns, such as a series of concentric rings, may also be included on the mask and imaged onto the sample.
30   The patterned regions of amplitude and phase masks are fabricated using deposition techniques well-known in the art, such as chemical vapor deposition, RF and magnetron sputtering techniques, and standard micro-lithographic (i.e., photo-lithographic) techniques.
35   These methods are described, for example, in

Semiconductor Lithography: Principles, Practices, and
Materials, Wayne M. Moreau (1988), and Wavefront
Engineering for Photolithography, Mark D. Levinson, the
contents of which are incorporated herein by reference.
5 Both square and sine wave patterned masks are also
available commercially from, for example, Sine Patterns
or Applied Image Inc. Phase-modulating masks may be
formed, for example, using glass etching techniques known
in the art, such as those described in the above-
10 mentioned references.

        Once the excitation and probe beams are diffracted
from the patterned region of the first mask, the second
mask is used to spatially filter the diffracted field to
allow selection of the diffracted orders which are to be
15 imaged onto the sample. Referring now to Figs. 5A and
5C, following diffraction by the first mask, the optical
intensities of the diverging sub-beams, indicated by the
ordinate axes in the figures, vary as a function of the
divergence along the z axis. The figures represent the
20 spatial intensity profile of the diffracted excitation
and probe sub-beams measured along a plane which is
adequately spaced from the first mask, thereby allowing
clear separation of the diffracted orders and the sub-
beams within each diffracted order. The zeroth
25 diffracted orders 100, 102 of both the excitation and
probe sub-beams, representing the spatial DC component of
the diffracted field, do not diverge and remain spatially
overlapped following interaction with the diffracting
mask. The +1 and -1 orders, indicated, respectively, by
30 brackets 104 and 104', contain the +1 and -1 probe 106,
106' and excitation 108, 108' sub-beams. The separations
between the DC components 100, 102 and the excitation and
probe sub-beams of the +1 and -1 orders, indicated by the
arrows 103 and 105, are a function of the configuration
35 of the pattern on the mask, the wavelengths of the

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excitation and probe fields, and the separation between
the plane of the diffracted field and the mask. In the
case where the pattern on the diffractive mask is
configured to generate multiple diffractive orders (i.e.,

5   a square wave diffracting pattern), probe 110, 110' and
excitation 112, 112' sub-beams will be present in the +2
and -2 diffractive orders indicated, respectively, by the
brackets 114 and 114'. Higher diffracted orders,
although possible, are not shown in the figure.

10   The second mask is chosen to have a transmission
function which spatially filters the diffracted pattern,
thereby selecting, for example, a single pair of
diffractive orders. Referring now to Figs. 5B and 5C, a
mask which allows selection of the +1 and -1 diffractive

15 orders has non-transmissive regions 120, 122, 122' which
block the DC and higher-order diffracted components,
thereby preventing these sub-beams from propagating onto
the sample. Transmissive regions 124, 124' are disposed
to allow four beams, i.e., the +1 and -1 orders 104, 104'

20 each containing the excitation 108, 108' and probe 106,
106' sub-beams, to propagate onto the sample. In
embodiments, the non-transmissive regions in the second
mask may be composed of an absorbing or reflecting
substrate, such as a metal or plastic plate, and the

25 transmissive regions may consist of apertures where the
substrate has been removed.

        The width of the transmissive region in the sec nd
mask, indicated by the arrow 126, is chosen to allow
passage of both the excitation and probe sub-beams of the

30 selected diffraction order. This width is dependent on
the cumulative spatial extension of the diffracted
excitation and probe sub-beams, and, as described
previously, is determined by the wavelengths of the
excitation and probe fields, the spacing of the

35 modulating regions in the diffracting pattern, and the

separation between the dispersed fields and the first
mask. Typically, the transmissive regi ns have widths of
between 0.5 and 2.0 cm.

During operation, the diffractive patterned
5 regions on the first mask are aligned with respect to the
spatial filtering patterns on the second mask so that the
two masks can preferably move vertically and in concert,
thereby allowing rapid, automated adjustment of the
different excitation fields. The masks should be mounted
10 so that the diffracting and filtering patterns are
aligned at the same height and positioned symmetrically
along the optical axis of the system. For example, the
two masks may be mounted on a mechanical translation
stage whose position can be controlled manually or by
15 using a motorized drive and a computer. In this manner,
data can be sequentially taken at a number of wavevectors
to allow determination of various points along the
dispersion curves of bulk and thin film samples.
Alternatively, in order to reduce the number of
20 components of the optical modulating system, both masks
can be formed on a single substrate. For example, the
diffracting, spatially periodic pattern may be formed on
one surface of a glass plate, and the spatially filtering
pattern may be formed on the opposing surface. In this
25 case, the diffracting and filtering patterns are
positioned relative to each other as described above, and
the substrate must be thick enough to allow the
diffracted sub-beams to adequately disperse before
impinging the spatially filtering surface.
30   Once data is collected for a particular
wavevector, the masks are translated so that new
diffracting and filtering patterns are used to generate
an excitation field at a new wavevector, and the data-
collection process is repeated. Alternatively, a single
35 pattern containing several distinct spatial frequenci s

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may be used to modulate the incident excitation beam, and a second mask is used to select the desired Fourier components of the fields to be imaged onto the sample. In this embodiment, multiple excitation and probe beams,

5 each corresponding to a different excitation wavevector, are diffracted by the first mask, and are then recombined on the sample and used to generate multiple signal beams, which may then be detected and analyzed. This allows the entire dispersion of the sample to be determined during a

10 single excitation probe event.

The optical sources and detection electronics which may be used with the optical modulating system have been described previously in J.A. Rogers et al., J. Appl. Phys. 75:1 (1994) and A.R. Duggal et al., U.S.S.N.

15 07/910,762, the contents of which are incorporated herein by reference. Briefly, in order to impulsively generate material motions in a sample (using, e.g., ISTS or ISBS), the excitation beam is pulsed, and may be generated using a light source which is Q-switched, mode-locked, or both.

20 The pulse duration of the excitation field must be short enough to impulsively stimulate material motions in the film. For example, in order to excite acoustic processes, the output pulse preferably has a duration of between 100 picoseconds and 5 nanoseconds. The energy of

25 the output pulse is preferably between 0.1 and 5 millijoules. In addition, the repetition rate of the pulses must be high enough to allow suitable data averaging (when necessary), but low enough to allow the thermal properties of the sample to recover between laser

30 shots. Preferably, the repetition rate is between 1 and 2000 Hz, with the rate being adjusted for measurement of different types of samples. For samples which easily damage, such as thin polymer films, it may be preferable to reduce the repetition rate of the excitation laser.

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In rder to created excited-state transient
gratings (e.g., gratings of electron-hole pairs, or other
excitonic species), the carrier frequency of the
excitation beam is such that it is absorbed by the
5 sample. If the excitation wavelength is below the
absorption energy of the sample, the beam may first be
passed through one or more non-linear optical devices,
such as a frequency-doubling or frequency-tripling
crystal, which can be used to generate higher-order
10 harmonics (e.g., second or third order harmonics) of the
fundamental frequency. Alternatively, if the sample is
excited using mechanisms which do not rely on optical
absorption (e.g., ISRS or ISBS processes), the excitation
light need not be absorbed by the sample.
15   Once excited, the time-dependent properties of the
sample are recorded by monitoring the time-dependent
diffraction of the probe beam, which is preferably
derived from a continuous wave (cw) single-mode laser
producing between 0.1 and 1 Watt in the visible frequency
20 range (e.g., 514 nm) with a flat intensity profile. In
certain embodiments, in order to measure the entire time
dependence of the transient grating induced in the sample
(which, e.g., may take place over several hundreds of
microseconds), a well-defined probe waveform is generated
25 by electro-optically modulating the cw probe beam with a
light modulator which controls both the duration and
shape of the probe waveform. Preferably, in this case, a
probe pulse having a square-wave profile is generated.
The waveform has a time duration slightly longer than the
30 time-dependent motions in the film. The pulse preferably
has a temporal duration on the order of between 1 and 100
microseconds. Alternatively, a Q-switched laser
producing a pulse duration greater than about 100 ns may
be used as the probe laser. In this case, the pulse may
35 be frequency doubled or tripled prior to interacting with

the sample. In still other embodiments, the diffracted
signal may be mapped out in a point-by-point basis, using
a pulsed probe beam as described in Duggal et al.,
U.S.S.N. 07/910,762.

5   The probe waveform diffracted from the transient
grating induced in the sample is preferably detected with
a time-resolving photodetector. This allows the entire
time dependence of the excited region of film to be
measured with a single probe waveform. For especially
10 weak signals, a lens may be used to focus the diffracted
beam on the optically active region of the detector,
thereby increasing the intensity of the signal. For
particularly noisy or weak signals, signal-enhancing
electronics, such as high-speed amplifiers, may be used
15 in combination with the photodetector. For signals
detected on a point-by-point basis, photodetectors having
long time constants may be used to generate the light-
induced signal.

         Light sources other than Nd:YAG lasers may be used
20 to optically excite the film. Suitable lasers include,
among others, Nd:YLF, ion (e.g., argon and krypton),
Ti:Sapphire, diode, CO_2, holmium, excimer, dye, and
metal-vapor lasers. Similarly, light sources other than
cw argon ion lasers may be used as the probe laser.
25 Alternative lasers include diode and krypton ion lasers.
Pulsed light sources which may be used to generate the
probe beam include Q-switched Nd:YAG, Nd:YLF,
Ti:Sapphire, diode, CO_2, holmium, excimer, dye, and
metal-vapor lasers.

30   The samples which may be monitored with the method
and apparatus described herein may be bulk (e.g., solids
such as metal or semiconductors), thin films (e.g.,
polyimide, semiconductor, or metal films), fluids,
surfaces or other samples exhibiting time-dependent
35 material motions. The material properties which can be

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determined in these samples include mechanical, elastic, (depth-dependent and/or anisotropic) diffusive, adhesion-based, thermal (e.g., thermal diffusivities) and viscous properties associated with the damping of acoustic waves.

5   In addition, electron relaxation lifetimes, electron-hole recombination times, exciton lifetimes, and bi-exciton lifetimes may additionally be determined in, for example, metal and semiconductor samples.

In bulk systems the dispersion of the acoustic

10   properties allows the frequency dependence of the mechanical (e.g., bulk or shear) modulus to be determined. Additionally, measurement of the thermal diffusion dynamics allows the thermal diffusivity for the bulk system to be determined. In thin film systems, the

15   acoustic information that is obtained allows determination of the degree of adhesion, delamination properties, and the elastic, shear, and longitudinal moduli, as well as anisotropies in these properties. Depth-dependent properties and residual stresses in thin

20   films can also be determined.

The following are examples of the use of the optical modulating system to generate and measure transient motions in bulk and thin film samples.

Examples

25   The material motions of thin polyimide film samples adhered to silicon substrates were measured by passing an excitation beam through the optical modulating system described herein, resulting in the excitation of a transient grating in the sample. Following excitation,

30   the temporal dynamics of the grating were monitored using a probe beam delivered to the sample using a separate optical system.

In the data reported, waveguide modes in the film were excited using a Q-switched, mode-locked, and cavity-

35   dumped Nd:YAG laser. The output pulse had an energy of 1

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millijoule, a wavelength of 1064 nm, a pulse duration of
100 ps, and a repetition rate of up to 1 kHz. The light
from this laser was first attenuated and then passed
through a lithium triborate (LBO) crystal to yield light
5   at 532 nm, which was then mixed with the remnant 1064 nm
radiation in a β-barium borate (BBO) crystal to yield
excitation pulses of approximately 20 microjoules at 355
nm. This light was then attenuated to yield ~1
microjoule pulses that were used for excitation of the
10 films.

The excitation pulses were focussed on the
patterned region of the mask using a cylindrical lens
having a focal length of 15 cm to produce a beam size of
about 1 cm (z direction) by 300 microns (x direction).
15 The patterned region permitted modulation of the
amplitude of the excitation beam, and consisted of
alternating light-absorbing regions spaced by transparent
regions, resulting in a pattern having a square-wave
spatial profile. In the patterned region, the light-
20 absorbing regions were spaced by a distance of 6 microns,
with each region having a width of 6 microns. The light-
absorbing regions of the second patterned region of this
same mask were spaced by a distance of 12 microns, with
each region having a width of 12 microns. The second
25 mask was spaced by a distance of 2 cm from the first
mask, and contained a series of two square openings for
spatial filtering of the diffracted excitation sub-beams.
In the first series of openings, the transmitting regions
had an area of 1 cm^2 and were spaced by a distance of 4
30 cm. The transmitting regions of the second series had an
area of 1 cm and were spaced by a distance of 2 cm.

The imaging system used to image the spatial
patterns of the masks onto the sample consisted of a
single lens having a focal length of 20 cm. The lens was
35 separated from the first mask by a distance of 40 cm.

The imaging lens was displaced by a distance of 40 cm
from the sample. Recombination of the excitation sub-
beams using this imaging system and the two masks
resulted in spatially varying optical excitations
5 patterns at the sample having wavevectors equal to the
spatial frequency of the patterned regions of the masks.
        Material motions in the film were recorded in
real-time by monitoring the time-dependent diffraction of
a probe pulse spatially overlapped with the induced
10 transient grating. The probe pulse had a duration of
about 150 ns, and was derived from Q-switched Nd:YAG
laser. Prior to irradiating the sample, the probe beam
was frequency-doubled to a wavelength of 532 nm. The
probe beam was then focussed at an angle of 15° to a 100-
15 micron diameter spot on the transient grating. The
diffracted component of the probe beam was measured with
a fast amplified photodiode (Antel; 2 GHz bandwidth).
The light-induced signal was then sent to a transient
digitizer (Tektronics DSA 602A; 1 GHz bandwidth),
20 resulting in generation of digital signal for analysis.
The combination of the photodiode and transient digitizer
effectively provided a 1 GHz-bandwidth window through
which the film's oscillatory and relaxational motions
were monitored.
25   Data was generated by passing the excitation beam
through the first set of patterns on the two masks,
signal averaging for 20 laster shots, and then
mechanically adjusting the masks so that the excitation
beam was modulated by the second set of patterns.
30 Referring now to Figs. 6A and 6B, typical data taken from
the silicon-bound polyimide films using the above-
identified optical system illustrates the time-dependent
nature of the measured signal. The oscillatory component
of the data is due to the coherent, periodic motions of
35 the excited waveguide modes. The difference in frequency

between the two data scans is due to excitation of the
film with different wavevectors. Damping of these modes,
shown in the data (after several hundred nanoseconds) as
a decrease in the amplitude of subsequent oscillations,
5 is due to viscous losses in the polyimide material. The
two data scans, taken with different excitation
wavevectors adjusted during a time period of just 19
seconds, demonstrate that the optical modulation system
can be used to change the wavevector of the excitation
10 pattern in very rapid fashion, and can additionally be
used to generate data having high signal-to-noise ratios.

In a separate experiment, the first and second
masks described above were used to sequentially modulate
the excitation and probe beams in order to monitor the
15 response of the liquid salol at room temperature. In
this case, the sample was optically excited throughout
the bulk (i.e., in the thick-grating regime) using the
fundamental frequency from the Nd:YAG laser described
above. The transient grating was probed using the output
20 from a cw single-mode Argon ion laser (Lexel 3500)
producing 1 Watt at 514 nm with a flat intensity profile.
This output was electro-optically modulated (Conoptics
380) to yield a square pulse having a temporal width of
100 microseconds. The signal beam was detected using the
25 photodetector and transient digitizer described above.
In this experiment, the excitation and probe beams were
made collinear prior to modulation with the diffracting
and spatial filtering masks, and 1:1 imaging optics (i.e.
$M = 1$) were used, thereby ensuring that the phase-
30 matching criteria were satisfied by the probe beam.

Referring now to Figs. 7A and 7B, two sets of data
were generated using a first mask with amplitude-
modulating regions 6 microns wide, and 6 microns apart.
The second mask used to filter the diffracted beam had
35 two openings, each with an area of 1 cm^2 and spaced by a

distance of 4 cm. The first order diffracted components
of th pattern on the first mask were imaged onto the
sample, resulting in a sinusoidally varying excitation
field having a spatial periodicity of 6 microns. The
5 diffracted signals were measured during short (i.e., 600
ns; Fig. 7A) and long (i.e., 110 microseconds; Fig. 7B)
time windows.

The high signal-to-noise ratios of the data scans
illustrates that the Bragg angle is accurately set using
10 the masks. (If the probe were not incident at the Bragg
angle, the diffracted signal would be too weak to
measure.) In the experiments, the residual probe sub-
beam overlapped with the signal beam was used as a finder
beam to allow facile alignment of the signal into the
15 photodetector. As before, the coherent oscillations in
the data were due to the induced acoustic processes in
the samples, while the long-time exponential decay is due
to thermal diffusion.

Other embodiments are within the scope of the
20 following claims.

What is claimed is:

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1.   A method of determining a property of a
sample, said method comprising:

(a) providing a beam of radiation and then passing
the beam through a pattern on a diffracting mask to form
5 at least two excitation sub-beams;

(b) overlapping at least two excitation sub-beams
on a region of the sample with an imaging system to
generate a spatially varying optical field which excites
a transient grating in the region of the sample;

10   (c) irradiating the transient grating with a pr be
beam oriented so that at least a portion of the probe
beam is diffracted by the transient grating;

(d) detecting the diffracted portion of the prob
beam with an optical detector to generate a light-induced
15 signal; and

(e) analyzing said light-induced signal from the
optical detector to determine the property of the sample.

2.   The method of claim 1, wherein the diffracting
pattern comprises alternating light-modulating regions
20 having at least one spatial frequency, and the excitation
beam is separated into at least a zeroth, +1, and -1
excitation sub-beam by diffracting the excitation beam
off of the light-modulating regions of the diffracting
pattern.

25   3.   The method of claim 2, wherein said
overlapping step further comprises the step of passing at
least the +1 and -1 excitation sub-beams through the
imaging system prior to overlapping the excitation sub-
beams on the sample.

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4.   The method of claim 3, wherein the imaging system images at least one of the spatial frequencies of the light-modulating regions of the diffracting pattern onto the sample to form the spatially varying optical
5 field.

5.   The method of claim 4, wherein at least one of the spatial frequencies of the light-modulating region and the spatial varying optical field are equivalent.

6.   The method of claim 1, wherein the excitation
10 beam is focussed onto the diffracting pattern prior to step (a).

7.   The method of claim 6, wherein the excitation beam is cylindrically focussed onto the diffracting pattern.

15   8.   The method of claim 1, wherein the probe and excitation beams are made collinear prior to step (a).

9.   The method of claim 8, wherein step (a) further comprises the step of separating the probe beam into at least two probe sub-beams by passing the probe
20 beam through the diffracting pattern on the first mask.

10.   The method of claim 8, wherein said probe sub-beams pass through the imaging system prior to irradiating the grating induced in the region of the sample.

25   11.   The method of claim 10, wherein the imaging system is a 1:1 imaging system.

12. The method of claims 1 or 9, wherein between steps (b) and (c) said excitation sub-beams are spatially filtered with a second mask.

13. The method of claim 12, wherein the first and
5 second masks are comprised in a single unit.

14. The method of claim 12, wherein said spatial filtering transmits the +1 and -1 excitation and probe sub-beams.

15. The method of claim 1, wherein said analyzing
10 step further comprises determining the dispersion of the sample.

16. The method of claim 15, wherein the dispersion is used to determine the mechanical, thermal, optical, or electronic properties of the sample.

15   17. The method of claim 16, wherein the mechanical property is one of adhesion, elastic moduli, stiffness, residual stress, and density.

18. The method of claim 15, wherein the dispersion is determined following inducing multiple
20 transient gratings in the sample with a single spatial varying optical field having multiple spatial frequencies.

19. The method of claim 15, wherein the dispersion is determined following sequentially inducing
25 multiple transient gratings in the sample with multiple spatial varying optical fields, each having a single spatial frequency.

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20.   A method of diffracting a probe beam off a
sample, said method comprising:

(a) providing a beam of radiation and then passing
the beam through a pattern on a diffracting mask to form
5 at least two excitation sub-beams;

(b) overlapping at least two excitation sub-beams
on a region of the sample with an imaging system to
generate a spatially varying optical field which excites
a transient grating in the region of the sample; and

10   (c) irradiating the transient grating with a probe
beam oriented so that at least a portion of the probe
beam is diffracted by the transient grating.

21.   An apparatus for diffracting a portion of a
probe beam off a sample, comprising:

15   means for generating a probe optical beam and an
excitation optical beam orientated along an optical axis,

a first diffracting mask comprising an optical
diffracting pattern, said diffracting pattern being
positioned along the optical axis and being configured so

20 that when irradiated with the excitation beam, said
pattern diffracts the excitation beam to generate at
least two excitation sub-beams;

an imaging system comprising at least one lens
positioned along the optical axis, said imaging system

25 configured to focus the excitation sub-beams onto a
region of the sample to generate a spatially varying
optical field which excites a transient grating in the
region of the sample, said grating allowing diffraction
of a portion of the probe beam off of the excited region

30 of the sample.

22.   The apparatus of claim 21, wherein said
diffracting pattern comprises a series of opaque regions

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spaced by a distance which allows diffracti n of visible
or infrared radiation.

23.   The apparatus of claim 21, wherein said
diffracting pattern comprises a series of regions etched
5 to a depth and spaced by a distance which allows
diffraction of visible or infrared radiation.

24.   The apparatus of claim 21, wherein said
apparatus further comprises a second, spatially filtering
mask comprising a pair of openings, said openings
10 positioned along the optical axis so that said spatially
filtering mask allows spatial filtering of said
diffracted excitation sub-beams.

25.   The apparatus of claim 24, wherein the
diffracting and spatial filtering masks are comprised in
15 a single unit.

26.   The apparatus of claim 24, wherein said
filtering mask comprises a plurality of pairs of opening.
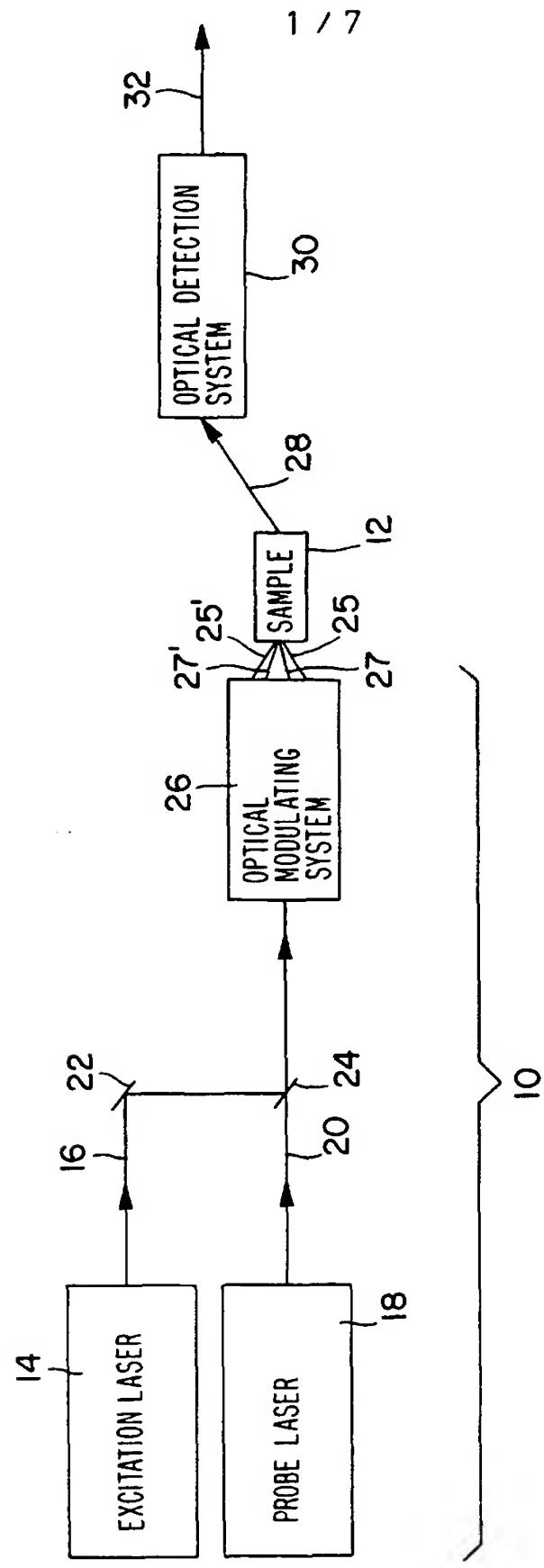
FIG. I
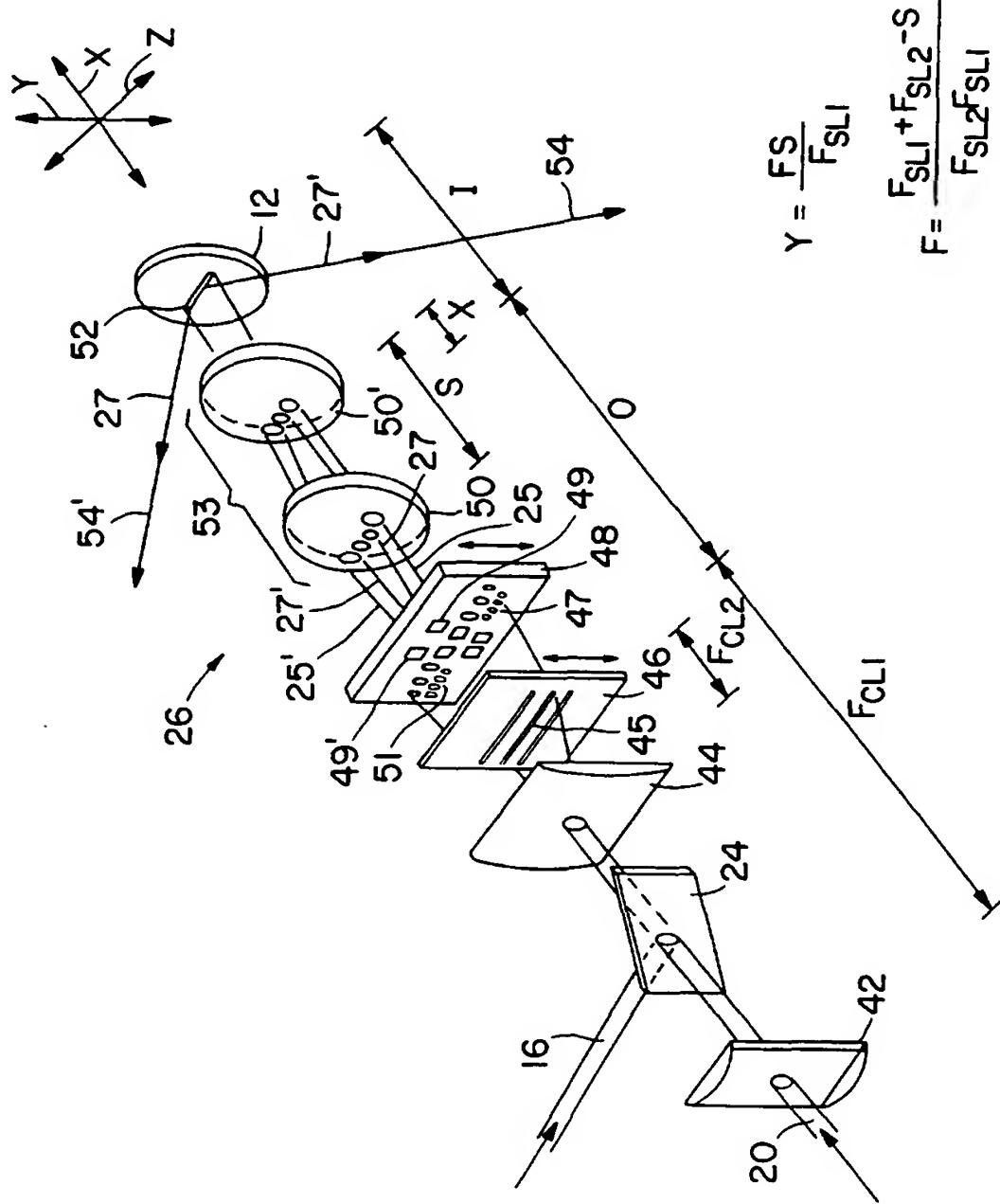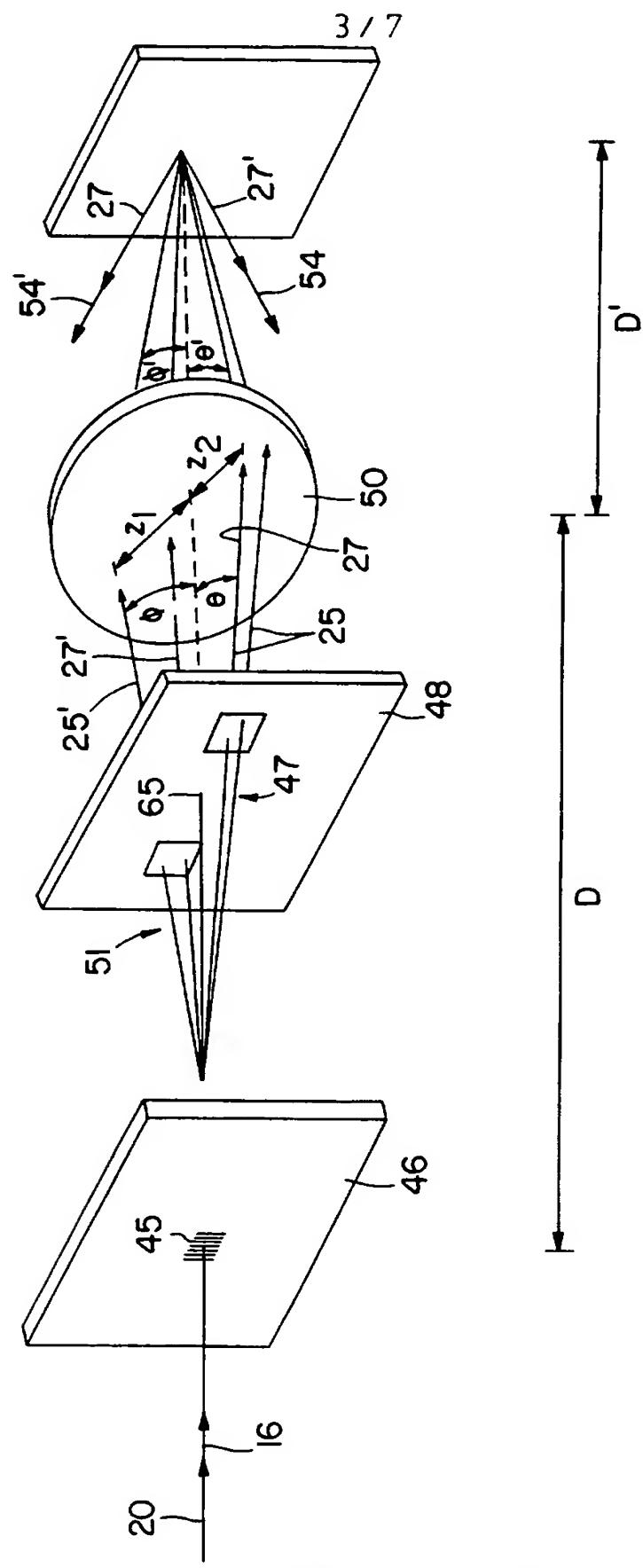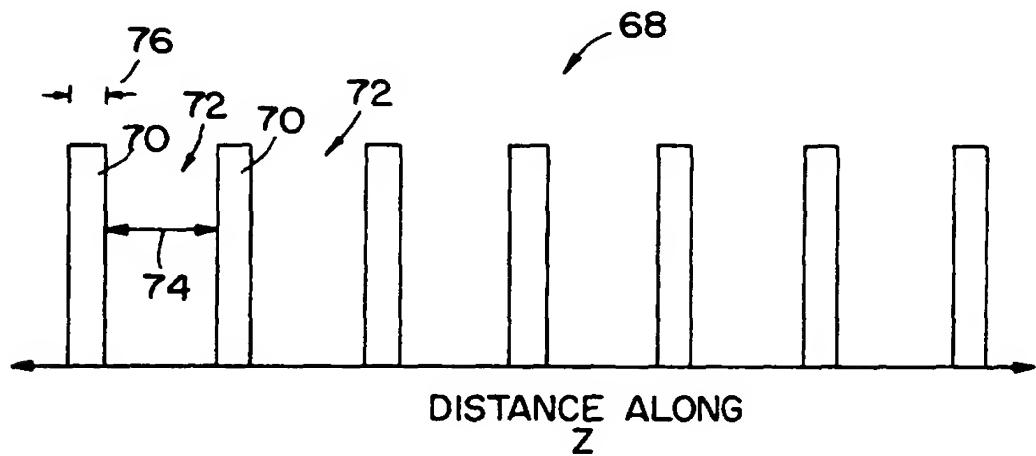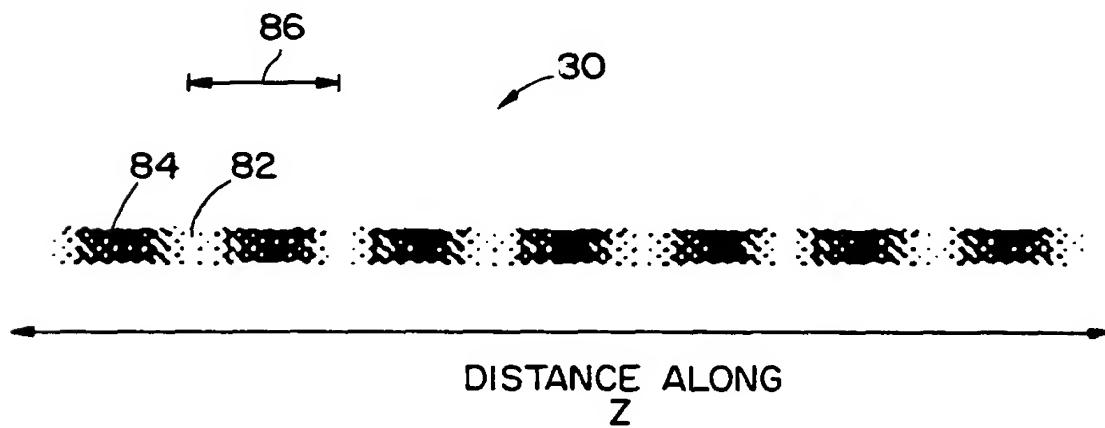
FIG. 2

$$Y = \frac{FS}{F_{SLI}}$$

$$F = \frac{F_{SLI} + F_{SL2} - S}{F_{SL2} F_{SLI}}$$

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FIG. 3

FIG. 4A

FIG. 4B

FIG. 5A

FIG. 5B

DISTANCE ALONG Z
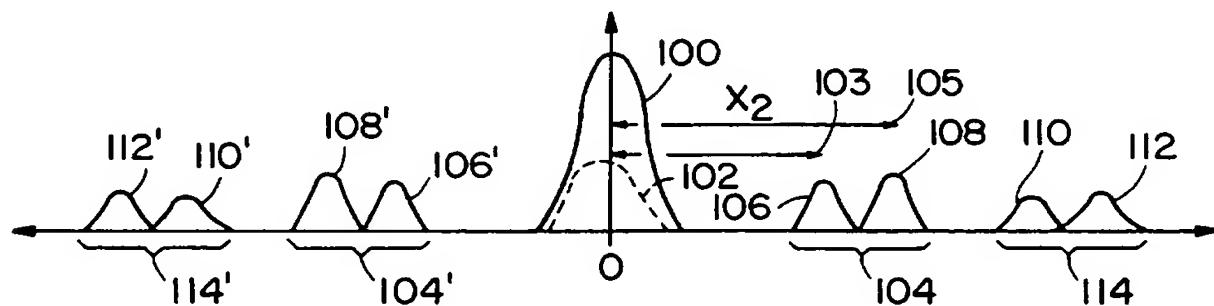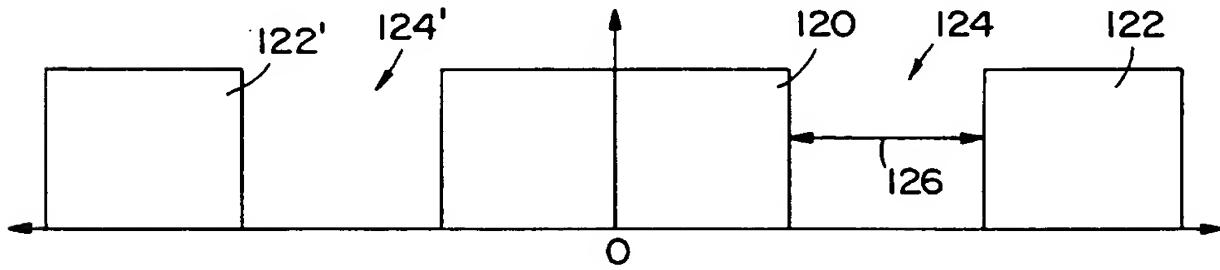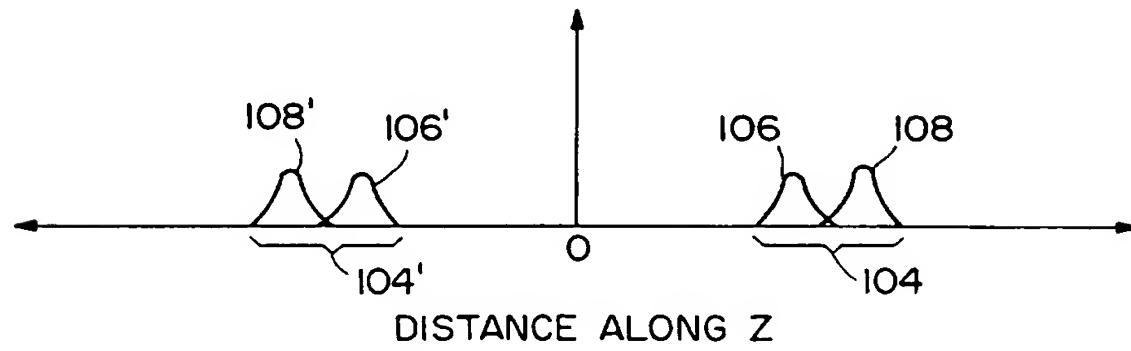
FIG. 5C
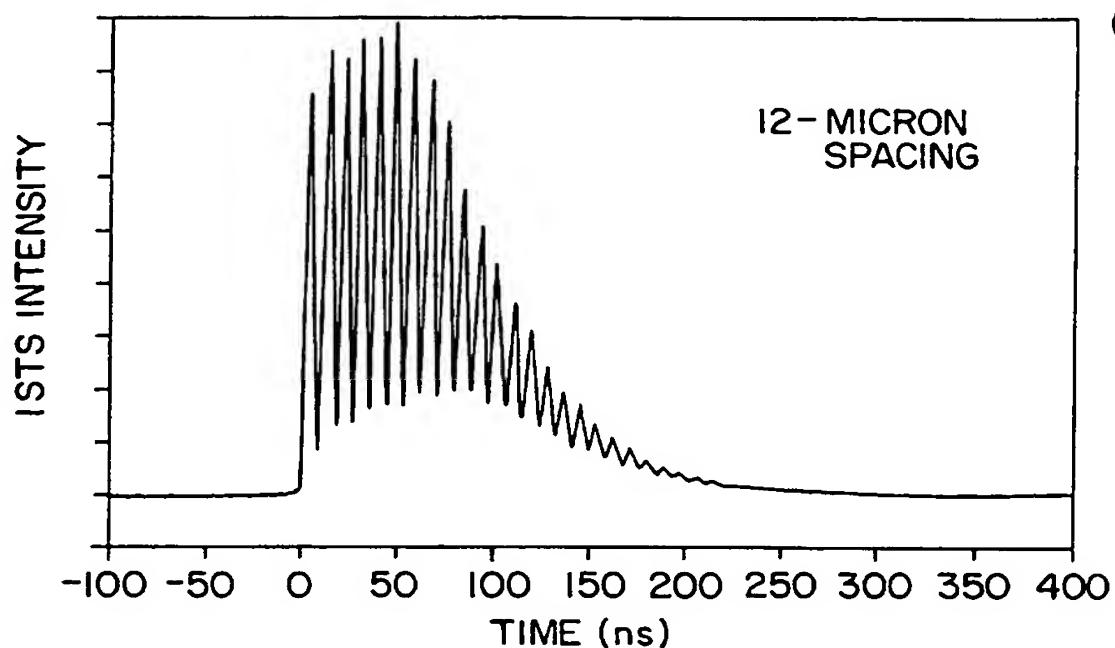
FIG. 6A
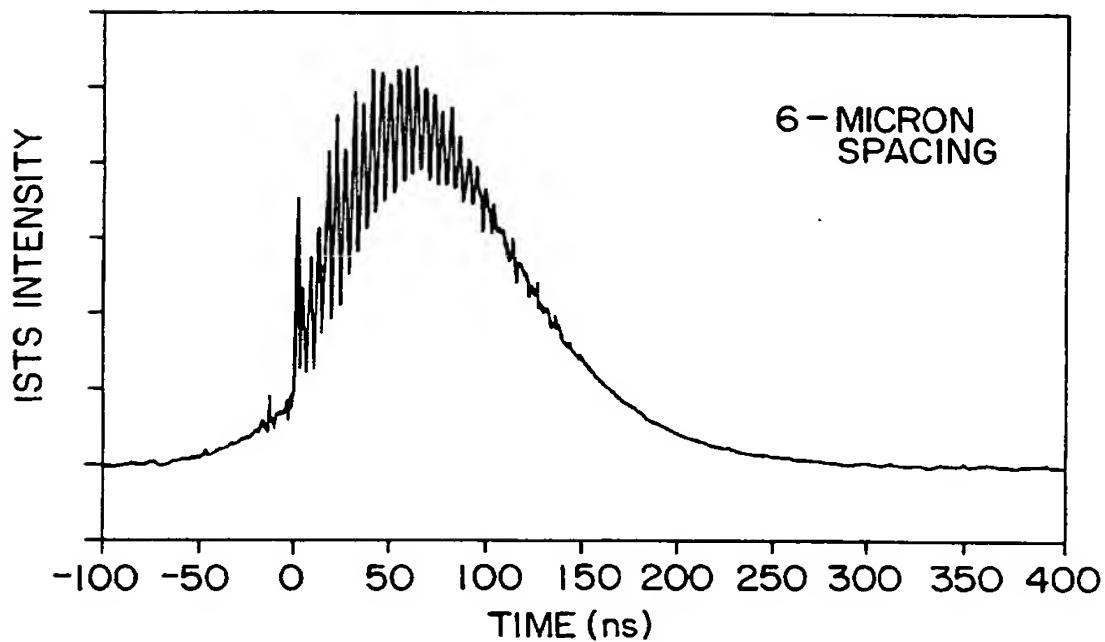
FIG. 6B
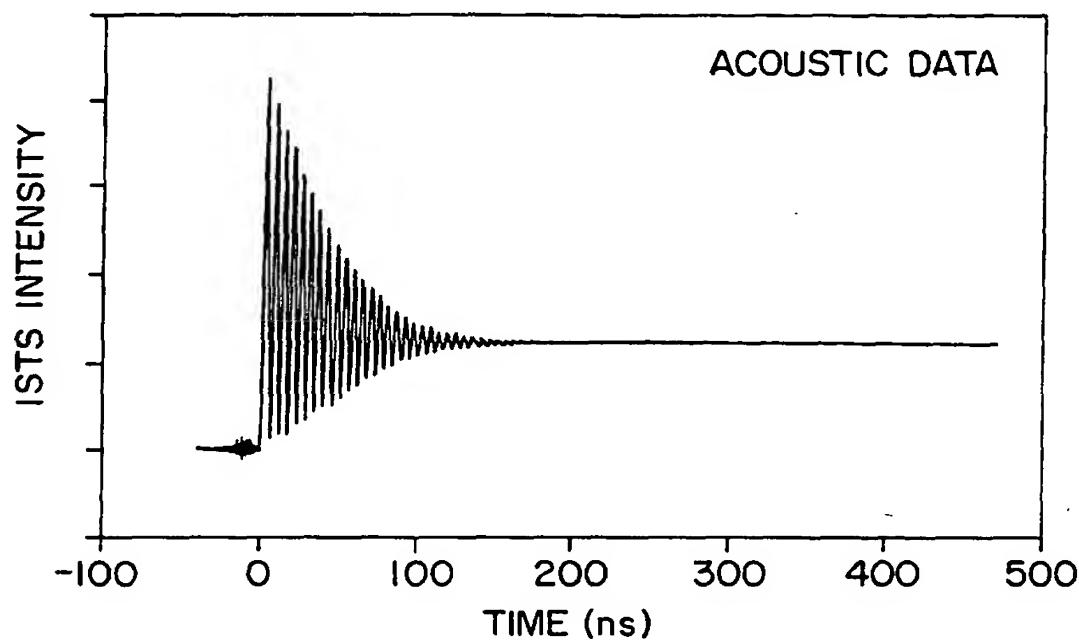
FIG. 7A
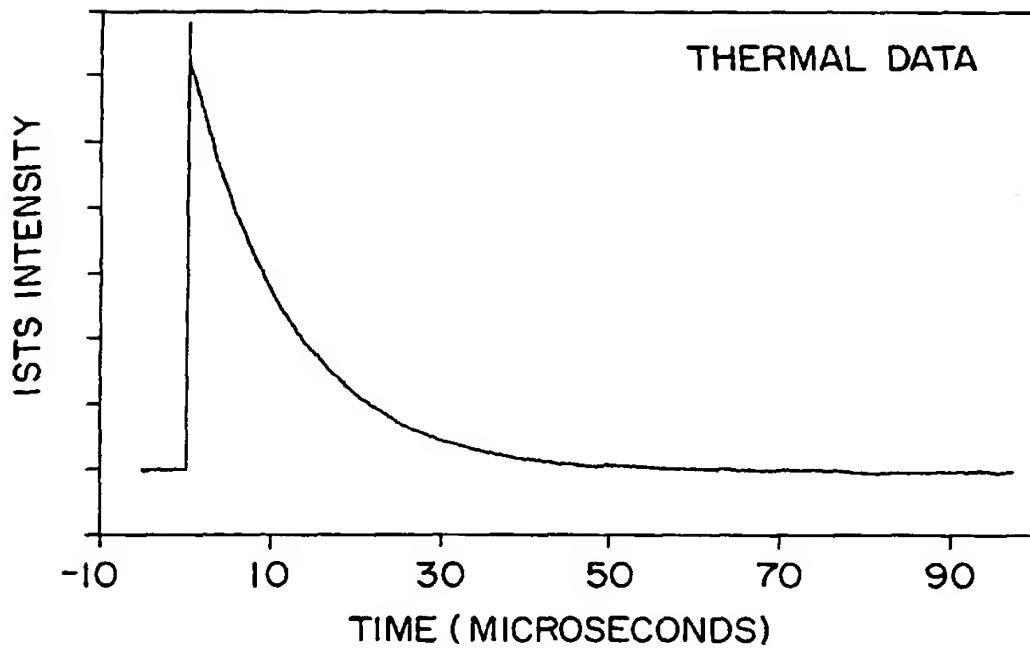
FIG. 7B

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :G01B 9/02

US CL :356/354, 356, 432, 237

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 356/354, 356, 432, 237

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS

search terms: transient grating, probe beam, excitation beam, diffraction

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US, A, 5,344,236 [FISHMAN]06 SEPTEMBER 1994, figures 2 and 3	1-11, 15-23,
A, P	US, A, 5,479,256 [TAMAI EL AL] 26 DECEMBER 1995.	1-26

☐ Further documents are listed in the continuation of Box C.   ☐ See patent family annex.

*	Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	
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Date of the actual completion of the international search	Date of mailing of the international search report
29 MARCH 1996	**22 APR 1996**

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